Future of LFR in Europe the ALFRED reactor

International Workshop of the SILER Project on Seismic Analysis of Lead-cooled Reactors

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Luigi Mansani
Luigi.mansani@ann.ansaldo.it
Development of a new reactor technology must follow gradual and progressive steps to reach maturity

- Identification of main issues related to the technology
- Small scale to Large scale experimental facilities
- Irradiation tests, fuel and materials development

and try to:

- Exploit full potential of the coolant
- Include from the beginning Safety in the Design
- Show sustainability of the fuel cycle
- Define and evolve a reference conceptual design of the FOAK
LFR Development History

- The first step in the development of a Lead Cooled Critical Fast Reactor in Europe started in 2006 with the EU - FP6 ELSY project, on the basis of previous projects already carried out in the frame of projects dedicated to Lead-Bismuth/Lead cooled Accelerator Driven Systems (XT-ADS, EUROTRANS, etc.)

- On February 2010 (EU - FP6 ELSY project terminated) a first reference configuration of an industrial size (600 MWe) LFR was available.
  ELSY was selected as one of the reference reactors in the SILER project for evaluating its behavior in case of seismic accident and for individuating possible countermeasures for limiting the reactor damage

- On April 2010 the LEADER project started its activities with the main goal to:
  - Improve the ELSY design toward a new optimized conceptual configuration of the industrial size plant, the **ELFR** conceptual design
  - Design a scaled down reactor, the LFR demonstrator – **ALFRED**, using solutions as much as possible close to the adopted reference conceptual design but considering the essential need to proceed to construction in a short time frame
  ALFRED has been selected as one of the reference reactors for seismic study in the ESNI+ project
• ALFRED – MAIN Design Guidelines

ALFRED will be connected to the electrical grid (Reactor Power ~125 MWe)
ALFRED design should be as much as possible based on available technology to speed up the construction time

ALFRED shall use structural materials compatible with the corrosive Lead used as coolant (Selected material AISI 316LN, T91, 15-15/Ti)

ALFRED design shall limit coolant flow velocity compatible with the erosive Lead used as coolant

ALFRED design solutions shall allow components to be removed from the Reactor Vessel to facilitate inspection, maintenance, replacement

ALFRED design solutions (especially for Safety and Decay Heat Removal function) should be characterized by very robust and reliable choices to smooth the licensing process

ALFRED Decay Heat Removal Systems shall be based on passive technology to reach the expected high Safety level (low primary system pressure drops to enhance natural circulation)
ALFRED - Core Configuration

- 171 Fuel Assembly
- 4 Safety Rods
- 12 Control Rods
- 108 Dummy Element
Two redundant, independent and diverse shutdown systems are designed for ALFRED (derived from MYRRHA design).

The Control Rod (CR) system used for both normal control of the reactor (start-up, reactivity control during the fuel cycle and shutdown) and for SCRAM in case of emergency:
- CR are extracted downward and rise up by buoyancy in case of SCRAM.
- During reactor operation at power CR are most of the time partly inserted allowing reactor power tuning (each rod is inserted for a maximum worth less than 1$ of reactivity).

The Safety Rod (SR) system is the redundant and diversified complement to CR used only for SCRAM.
- SR are fully extracted during operation at power.
**ALFRED - Upper and Lower Core Support Plates**

**Lower core support plate**
Box structure with two horizontal perforated plates connected by vertical plates.
Plates holes are the housing of FAs foots.
The plates distance assures the verticality of FAs

**Upper core support plate**
Box structure as lower grid but more stiff
It has the function to push down the FAs during the reactor operation
A series of preloaded disk springs presses each FA on its lower housing

Hole for Instruments
ALFRED - Inner Vessel

Upper grid

Lower grid

Pin

Inner Vessel assembly
ALFRED - Steam Generator

- Bayonet vertical tube with external safety tube and internal insulating layer

- The internal insulating layer (delimited by the Slave tube) has been introduced to ensure the production of superheated dry steam

- The gap between the outermost and the outer bayonet tube is filled with pressurized helium to permit continuous monitoring of the tube bundle integrity. High conductivities particles are added to the gap to enhance the heat exchange capability

- In case of tube leak this arrangement guarantees that primary lead does not interact with the secondary water

- Flexibility of materials in terms of compatibility with Lead and Water
### ALFRED - Steam Generator Geometry & Performances

#### Steam Generator Geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of coaxial tubes</td>
<td>4</td>
</tr>
<tr>
<td>Slave tube O.D</td>
<td>9.52 mm</td>
</tr>
<tr>
<td>Slave tube thickness</td>
<td>1.07 mm</td>
</tr>
<tr>
<td>Inner tube O.D</td>
<td>19.05 mm</td>
</tr>
<tr>
<td>Inner tube thickness</td>
<td>1.88 mm</td>
</tr>
<tr>
<td>Outer tube O.D</td>
<td>25.4 mm</td>
</tr>
<tr>
<td>Outer tube thickness</td>
<td>1.88 mm</td>
</tr>
<tr>
<td>Outermost tube O.D</td>
<td>31.73 mm</td>
</tr>
<tr>
<td>Outermost tube thickness</td>
<td>2.11 mm</td>
</tr>
<tr>
<td>Length of exchange</td>
<td>6 m</td>
</tr>
<tr>
<td>Number of tubes</td>
<td>510</td>
</tr>
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</table>

#### Steam Generator Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removed Power [MW]</td>
<td>37.5</td>
</tr>
<tr>
<td>Core outlet Lead Temperature [°C]</td>
<td>480.0</td>
</tr>
<tr>
<td>Core inlet Lead Temperature [°C]</td>
<td>401.5</td>
</tr>
<tr>
<td>Feedwater Temperature [°C]</td>
<td>335.0</td>
</tr>
<tr>
<td>Immersed bayonet steam outlet T [°C]</td>
<td>451.5</td>
</tr>
<tr>
<td>Steam Plenum Temperature [°C]</td>
<td>450.1</td>
</tr>
<tr>
<td>SG steam/water side global ∆p [bar]</td>
<td>3.3</td>
</tr>
</tbody>
</table>

![Steam Generator Thermal Cycle](chart.png)
Primary pump is an axial mechanical pump, always running at constant speed, with blade profile designed to achieve the best efficiency

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ALFRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate, kg/s</td>
<td>3247.5</td>
</tr>
<tr>
<td>Head, m</td>
<td>1.5</td>
</tr>
<tr>
<td>Outside impeller diameter, m</td>
<td>0.59</td>
</tr>
<tr>
<td>Hub diameter, m</td>
<td>0.39</td>
</tr>
<tr>
<td>Impeller speed, rpm</td>
<td>315</td>
</tr>
<tr>
<td>Number of vanes</td>
<td>5</td>
</tr>
<tr>
<td>Vane profile</td>
<td>NACA 23012</td>
</tr>
<tr>
<td>Suction pipe velocity, m/s</td>
<td>1.12</td>
</tr>
<tr>
<td>Vanes tip velocity, m/s</td>
<td>9.8</td>
</tr>
<tr>
<td>Meridian (at impeller entrance and exit) velocity, m/s</td>
<td>2.0</td>
</tr>
</tbody>
</table>
ALFRED - Reactor Vessel

- Cylindrical vessel with a torospherical bottom head anchored to the reactor pit from the top
- RV is closed by a roof that supports the core and all the primary components
- RV upper part is divided in two branches by a “Y” junction: the conical skirt (cold) that supports the whole weight and the cylindrical (hot) that supports the Reactor Cover
- A cone frustum welded to the bottom head has the function of bottom radial restraint of Inner Vessel

Main Dimensions

- Height, m: 10.13
- Inner diameter, m: 8
- Wall thickness, mm: 50
- Design temperature, °C: 400
- Vessel material: AISI 316L

Cover flange
Support flange

Inner Vessel radial support

Main Dimensions
Power: 300 MWth
Primary cycle: 400-480 °C
Secondary cycle: 335-450 °C
ALFRED - Decay Heat Removal Systems

- **DHR Systems**
  - **One non safety-grade** system, the secondary system, used for normal decay heat removal
  - **Two independent, high reliable passive and redundant safety-related** Decay Heat Removal systems (DHR N1 and DHR N2):
    - in case of unavailability of the secondary system, the DHR system N1 is called to operate and
    - in the unlike event of unavailability of the first two systems, the DHR system N2 is called to operate
  - **DHR N1:**
    - *Isolation Condenser* system connected to 4 out of 8 SGs
  - **DHR N2:**
    - *Isolation Condenser* system connected to the other four SGs
    - Considering that, each SG is continuously monitored, ALFRED is a demonstrator and a redundancy of 266% is maintained, the Diversity concept could be relaxed

- **DHR Systems features:**
  - **Independence:** two different systems with nothing in common
  - **Redundancy:** three out of four loops (of each system) sufficient to fulfil the DHR safety function even if a single failure occurs
  - **Passivity:** using gravity to operate the system (no need of AC power)
ALFRED - Isolation Condenser Heat Exchanger

- Upper and lower spherical header diameter 560 mm
- Tube diameter 38.1 mm
- Number of tubes 16
- Average tube length 2 m
- Material Inconel 600
**ALFRED - DHR System Performances**

4 Loops in operation (Maximum performances)
- Lead temperature < nominal
- Time to freeze ~ 4 hours

3 Loops in operation (Minimum performances)
- Lead Peak Temperature ~ 500°C
- Time to freeze > 8 hours
ALFRED - Secondary System

- Power conversion system based on superheated cycle
- with dual turbine configuration, three extractions in the HP and in the LP with an axial outlet
- Net cycle efficiency greater than 41%

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant net output, MWe</td>
<td>125</td>
</tr>
<tr>
<td>Cycle Net Efficiency, %</td>
<td>41</td>
</tr>
<tr>
<td>SG Mass Flow, kg/s</td>
<td>192.7</td>
</tr>
<tr>
<td>SG Pressure outlet, MPa</td>
<td>18.2</td>
</tr>
<tr>
<td>SG Pressure inlet, Mpa</td>
<td>18.8</td>
</tr>
<tr>
<td>SG Temperature outlet, °C</td>
<td>450</td>
</tr>
</tbody>
</table>

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ALFRED - Reactor Building: Vertical Section
ALFRED - Implementation plan

ALFRED realisation includes several phases

- First of all set-up of an international consortium (2013)
  - Site for construction has been already chosen (Mioveni in Romania)
  - First consortium act, according to ESNI Implementation plan, is to search funding

- Several design steps have been individuated:
  - Conceptual design, LEADER project (2010-2013)
  - Basic design, siting and pre-licensing
  - Detailed design and licensing
  - Components construction, civil engineering, on site assembly and commissioning

- Support R&D program will provide answers to remaining technical challenges
March 2011

- Romanian Minister of Energy wrote a letter to LEADER Project coordinator proposing to host ALFRED in Romania
- Ansaldo answered to Romanian Minister welcoming Romanian proposal and informed ESNII members

June 2013

- Sub-secretary of the Italian Minister for Economic Development wrote to commissioner Oettinger highlighting the importance of ALFRED in the European context and the intention to use synergies between RTD and infrastructural funds for ALFRED Project

August 2013

- Commissioner Oettinger answered welcoming the Italian/Romanian proposal and highlighted the importance and the usefulness of the synergies to pool resources and reach the critical mass for project deployment

December 18th 2013

- FALCON consortium was set-up by Ansaldo Nucleare, ENEA and ICN

Mioveni, Romania has been chosen as construction Site for ALFRED
Phase 1 (first 18th months; in-kind contributions), optimization of the cooperation between the PARTIES through strategic management, governance, financial and technical work

- **Sharing of information and technical review**  
  ANSALDO  
  Main activity include a technical review of ALFRED
- **Licensing and siting preliminary review**  
  ICN  
  First steps with the Safety Authority
- **Cost estimate and schedule review**  
  ANSALDO  
  Overall project cost and schedule
- **Assessment of financial instruments**  
  ICN  
  Pave the way for infrastructural funds
- **Roadmap and implementation plan**  
  ENEA  
  Overall Roadmap and ancillary facilities
- **Promotion initiatives and coordinated actions**  
  ENEA  
  Dissemination and coordinated actions
• **FALCON Phases:**

- **Phase 2** (Basic Design, Pre-licensing, Site Selection) 2015-2018
  - Resolution of R&D critical issues
  - Basic Design and support for Preliminary Safety Analysis Report
  - Pre-licensing activities, draft of the Preliminary Safety Analysis Report
  - Confirmation and Characterization of the Plant Site for construction

- **Phase 3** (FEED, Licensing) 2018-2022
  - Front END Engineering and Design
  - Lots definition, Technical Specification and Tendering
  - Site preparation
  - Licensing

- **Phase 4** (Construction, Pre-operational tests, Commissioning) 2022-2025
  - Detailed Design and Construction
  - Licensing
  - Pre-operational Tests
  - Commissioning

- **Phase 5** (ALFRED full Operation) 2026-....
  - ALFRED connection to the Grid
Due to the strong interest already manifested by several European Organizations a Memorandum of Agreement (MoA) has been defined to anticipate technical work already scheduled for the second phase of FALCON:

The interested organization can:

- Contact one of the FALCON members
- Agree on a technical activities program
- Sign the MoA with the FALCON member

All contributions in this phase are expected to be of an in-kind nature.

The goal is to constitute a pan-European network of organizations interested in the LFR technology development and ALFRED construction well coordinated by FALCON consortium.
FALCON Consortium

CV-REZ (Rez, Czech Republic) letter of intent to join FALCON received; FALCON members welcome CV-REZ, Signature formalities under way

MoA with FALCON Member

CRS4 (Sardinia – Italy - MoA Signed) proposing activity, already started, with CFD tools to support ALFRED design

NRG (Petten, The Netherlands - MoA final text received on Sept. 2) proposing activities on material irradiation and CFD analysis

SRS (Rome, Italy) proposing studies on DHR and Fuel Handling

IIT (Milan, Italy) proposing further studies on their PLD process used to deposit alumina layer on steel

KIT (Karlsruhe, Germany - formalization of the agreement with ENEA ongoing) proposing many activities on Lead Technology, Safety Analysis, Computer Code Validation, etc.

Genoa University (Chemical department) proposing activities on Lead Chemistry

Additional contacts for MoA

CIRTEN (Inter University Consortium for Technological Nuclear Research, Italy); GRS (TSO, Germany); KTH (University, Sweden); IRSN (TSO, France)
Thank you for your attention.